STATE OF OHIO
FRANK J. LAUSCHE, GOVERNOR
DEPARTMENT OF NATURAL RESOURCES
A. W. MARION, DIRECTOR
DIVISION OF GEOLOGICAL SURVEY
JOHN H. MELVIN, CHIEF

INFORMATION CIRCULAR No. 10

A Program of Activities and Research in Coal Geology

By GILBERT H. CADY
Consultant in Coal Geology

COLUMBUS • 1952

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INTRODUCTION

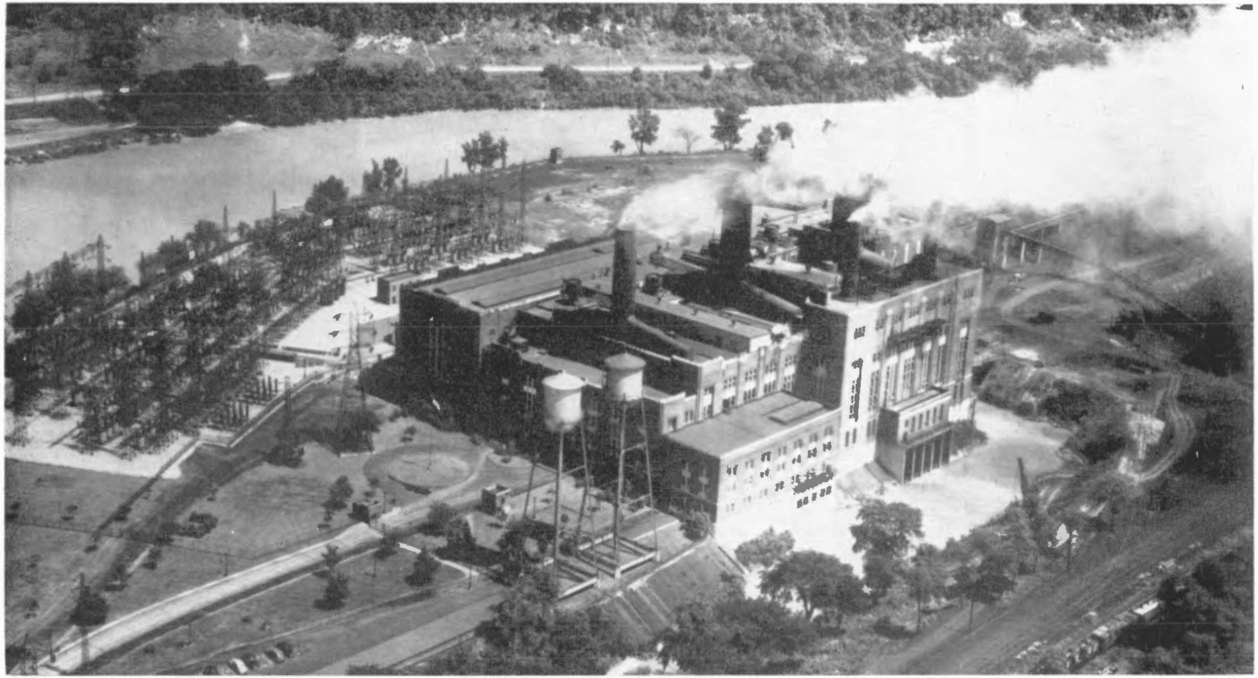
THE STATE OF OHIO is one of the most important among the coal mining states. In 1950 it ranked fifth[1] in coal production with an output of 36,977,932 tons[2], which was about 6.4 per cent[3] of the total production of coal in the United States*. Because the coal deposits of Ohio are of relatively easy access, large quantities lying near the surface, shallow, small, but successful mining operations have been possible with relatively small capital investment. Consequently the number of mines operating in Ohio is relatively large in comparison with the total production, and since many operations have been small, traces of abandoned mines are exceedingly numerous in the coal field. This points to the fairly widespread importance of the coal deposits in the southeastern part of the State where the coal is found.

A few statistical items will give some idea of the special characteristics of the local industry. During 1950, 840 mines of all varieties, truck and railroad mines, stripping and underground mines, operating in the State produced the tonnage given above. In comparison, the 55,346,000[4] tons produced in Illinois in 1950, this state being next higher than Ohio in order of production, represented the output of only 337 mines of which the "local" or truck mines, not shipping by railroad, produced only 2,834,055[5] tons or 5.1 per cent. In Ohio the mines not shipping by railroad, to the number of 540[6], produced 10,235,682 tons in 1950 or 27.7 per cent of the total yield. This indicates the relative importance of small, short-lived operations in Ohio as does also the fact that of the 705 mines in operation in Ohio as recently as 1946[7] only 256 (36.3%) are recorded in the coal report of 1950.

Small mining operations are of importance, but so likewise are the larger and more permanent operations. This is indicated by the fact that 36.9 per cent (13,635,381 tons) of the total tonnage in 1950 represented the output of only 1.7 per cent (14) of the mines, and 37 mines (4.4%) provided 55.5 per cent (20,525,274 tons) of the coal output[8].

The relatively easy accessibility of the coal in Ohio is also indicated by the fact that in 1950 60.6 per cent of the production (22,393,535 tons)[9] was recovered by strip mining. In 16 out of

*According to the Annual Coal Report for 1951 the total Ohio coal production was 37,816,708 tons.



Courtesy of Ohio Power Company

FIGURE 1. Philo Plant, Ohio Power Company, on Muskingum River, 10 miles south of Zanesville. It represents an investment of more than $50,000,000 and its nine generating units are capable of producing 405,000 kilowatts of electric energy. When operating at full capacity, Philo Plant burns about five tons of coal a minute, or enough every three minutes to heat the average home for a year.

the 26 counties from which production was reported in that year the coal mined by stripping accounted for 75 per cent of the output. In six counties, Mahoning, Noble, Portage, Scioto, Washington, and Wayne, 99 to 100 per cent of the production was by strip mining in 1950. The number of strip mines for that year was reported as 314.*

Coal means a great deal to the industrial life of Ohio. This is borne out by the fact that the use of coal in the production of electric energy in Ohio has been at the following rate: 1946—98.6%; 1947—99.0%; 1948—99.1%; 1949—97.7%; 1950—98.6%; 1951—99.1%. Numerous large steam-generated electric plants are scattered throughout Ohio. Thus Ohio coal is making a very important contribution to the production of electrical energy in this State. (Fig. 1.)

The mining of Ohio coal also provides important support to the railroads operating in the State. In 1950 about 25,500,000[10] tons of coal were shipped by rail, requiring the use of over 500,000 50-ton railroad cars. It is estimated that Ohio coal freight revenue amounted to about $40,000,000 for 1945[11] when about the same amount of coal was shipped by rail as in 1950.

Coal is an important item in the domestic fuel consumption in Ohio. It is probably correct to say that hundreds of thousands of homes in the State depend upon Ohio coal. Because of the expansion in the use of the underfeed type of stoker in homes, there has been in recent years a great development in the preparation of special coal for such appliances. This has not only benefited the manufacturers of stokers but has undoubtedly increased or at least helped to maintain the domestic market for Ohio coals, both because of the automatic nature of the appliance and because the stokers made it possible to burn the high volatile Ohio coals with little or no smoke.

It would be possible to continue to much greater length presenting evidence of the importance of the coal resources of Ohio to the life and industry of the State. The manner of the occurrence of

*376 Licenses for strip mining were issued in 1951 according to the Ohio Annual Coal Report for 1951, P. 35, issued by the Division of Mines.

the coal, the thickness, number, and geographic extent of the coal beds, the quantity of resources represented, the extent to which these resources actually represent potentially recoverable energy, and the probable life of this source of relatively cheaply produced energy are matters of importance to this commonwealth, although, because of the apparent easy availability of coal supplies, the ordinary citizen gives them little more consideration than he does to supplies of fresh air, pure water and abundant sunshine.

But coal is in a different category than air, water, and sunshine, for coal, unlike these other necessities, does not occur in ever renewing supply. Every million tons of coal removed from the initial reserve adds to the value of the balance, and makes of constantly increasing importance the quantity, quality and ease of recovery of such reserves. In general, it should be realized that the coal mining industry tends to be attracted to the best available sources of supply. But conditions of operation change with time, so that coal formerly thought unrecoverable because of shallow cover is now much regarded as particularly valuable by those whose interest is in open-cut or stripping operations.

There is as yet relatively little interest in coal beds that lie below a depth of 500 feet. The deepest operating mine in the State has a depth of 452 feet. (Nelm's Mine, Youghiogheny and Ohio Coal Company.) The next deepest operation on record was a mine at Canaanville with a depth of 440 feet[12]. Interest in the more deeply lying coal beds may not be long deferred.

Recent developments in the processes of coal cleaning have made it possible to operate profitably beds which, because of impurities, were formerly regarded practically worthless.

The thickness of beds which can now be operated with profit is in general about 3 feet. In Ohio the thinnest beds mined by mines producing as much as 200,000 annually is 30-36 inches. Only seven such mines are in operation. Smaller mines are known to have been worked in beds as thin as 18 inches where the coal possessed particularly desirable characteristics, such as an unusually low ash content.

Since it is impossible to forecast the extent of improvements in method of energy recovery, it is therefore impossible to achieve

FIG. 2. Photograph of a thin section of splinty bituminous coal showing many large and small plant spores.

any accurate estimate of the available energy that they represent. It is possible, however, to determine with considerable accuracy a great many important facts in regard to the occurrence of the coal beds. Their relation to one another in the geological succession, the thicknesses of the individual beds and the distribution of variations in thicknesses; the nature of the overlying and underlying rock so far as this affects the mining process; the chemical and physical characteristics and attributes of the coals themselves, the nature of the mineral impurities; and various other facts about the coal beds having a bearing on their absolute and relative values, provided full advantage is taken of opportunities to obtain such information. Such knowledge is of permanent value and not only assists those who are interested in the possibility of profitable commercial development of the natural resources but will tend to provide protection to land owners against fraudulent exploitation, which, fortunately, is rare.

Besides the importance of having as complete information as it is possible to obtain concerning the occurrence of the coal beds, information concerning the characteristics of the coal itself is also of great importance. Coal of medium rank, such as the banded, high volatile bituminous coal of Ohio, has far from the uniform composition commonly ascribed to the generalized substance coal. Physical examination of coal with the microscope and other physical instruments and methods and the application of various physical tests reveals a great diversity in the makeup of a block of coal, which is only partly indicated by what can be seen through the microscope in a thin section of a piece of coal. (See Fig. 2.)

With proper manipulation and chemical treatment it is possible to disintegrate the closely knit fabric of the coal and to release as individual entities various coalified fossil-plant tissues and secretions which by their presence demonstrate the diversity of the composition of the coal.

Nor is coal entirely uniform in chemical character. Coal consisting predominately of coalified wood (Fig. 3) differs from coal which consists largely of waxy or resinous materials, as is shown by the well known differences that distinguish ordinary banded bituminous coal (Fig. 4A) from coal of the cannel type (Fig. 4B). Splint coal (Fig. 4C) likewise possesses quite definite individuality with its blocky structure, dull, commonly unbanded appearance, and absence of coking properties.

Microscopic studies also reveal much about the nature and occurrence of mineral matter in coal, thus producing facts that are of much importance in estimating the possibilities of coal cleaning (Fig. 5).

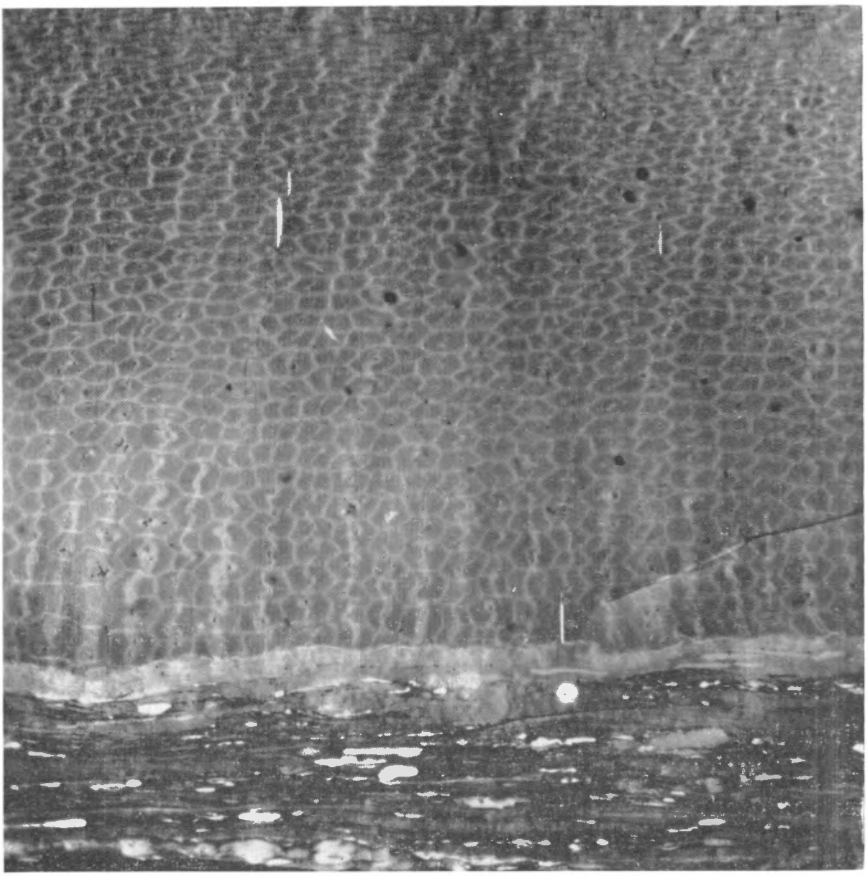


Photo by U. S. Bureau of Mines

FIG. 3. Microphotograph of a part of a thin section, from the Upper Freeport coal bed, consisting predominantly of coalified wood, showing cellular structure of the woody tissue.

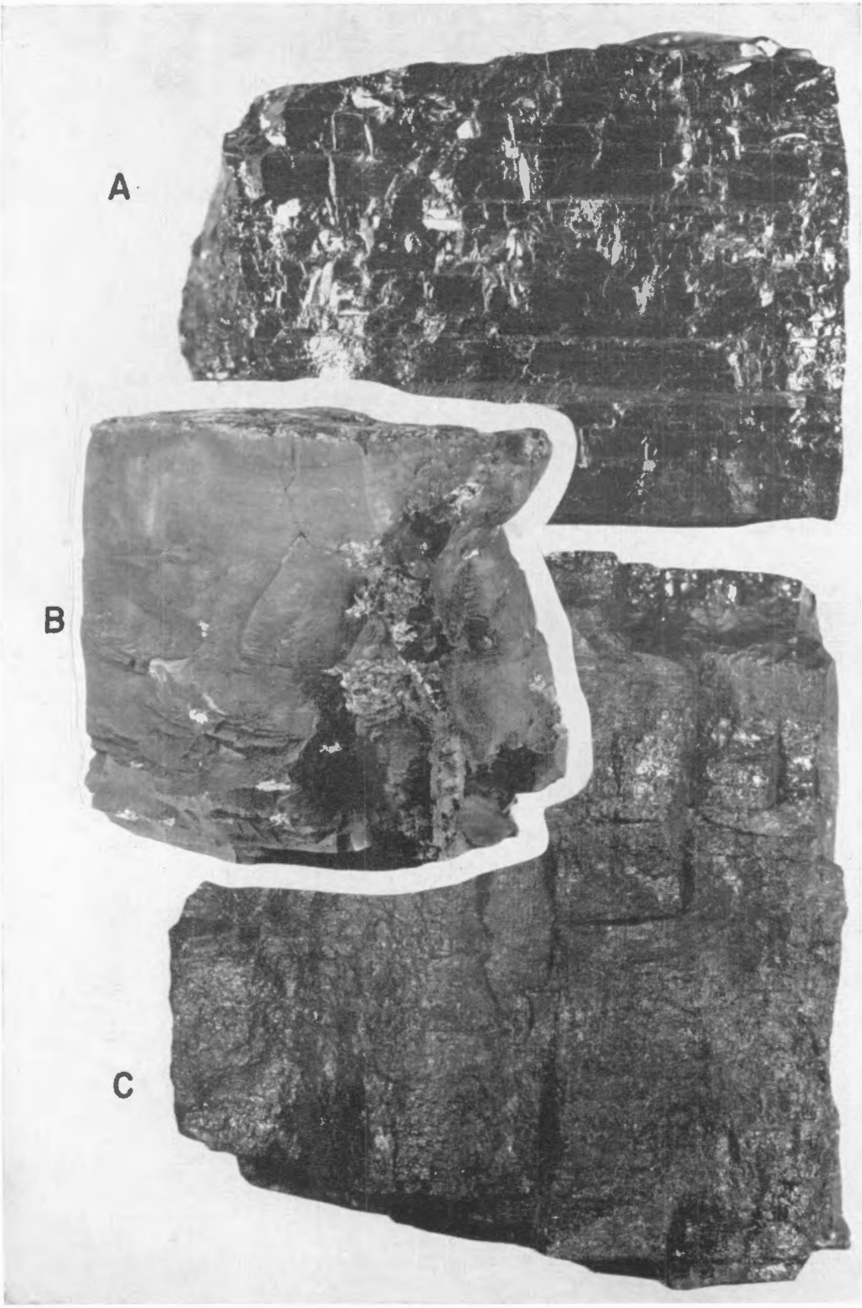


Photo by Illinois State Geological Survey

FIG. 4 A, B, C. (A) Banded bituminous coal from Franklin County, Illinois. (B) Cannel coal from Westmoreland County, Pennsylvania. (C) Splint coal, Kenawha County, West Virginia. Approximately one-half actual size.

Considerable space might be taken here in presenting evidence of the diversity of the physical constitution of bituminous coal such as is found in Ohio. This subject will, however, be treated at length later in this circular for those who care to pursue the matter further.

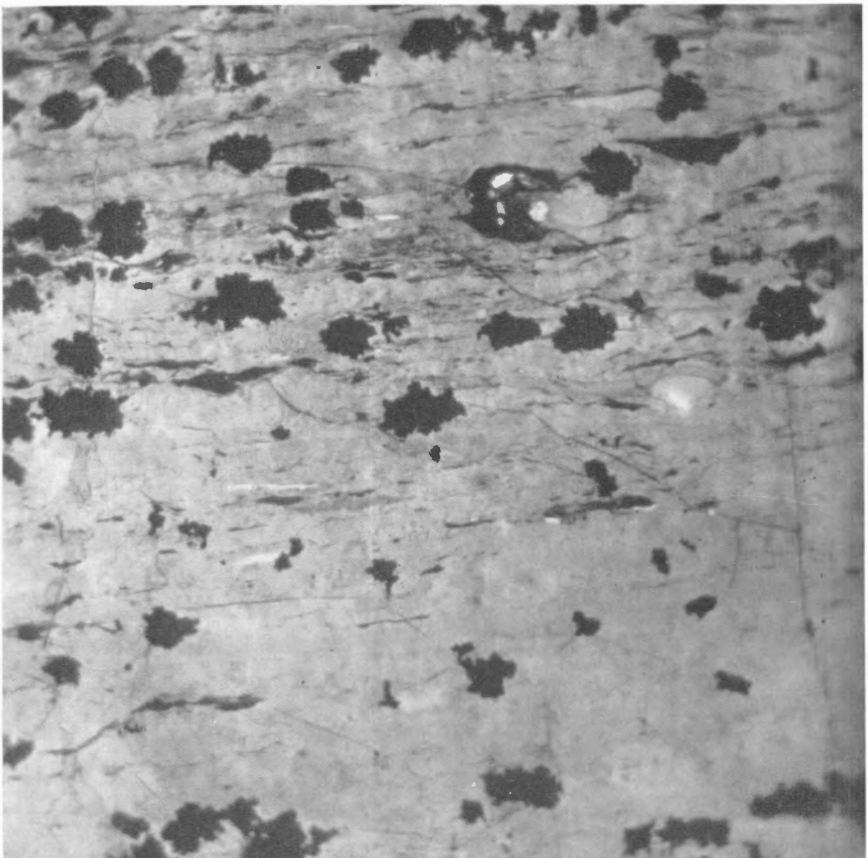


Photo by U. S. Bureau of Mines

FIG. 5. A thin section of bituminous coal showing disseminated pyrite in coal, Pittsburgh bed coal, Washington County, Penn.

AVAILABILITY OF INFORMATION CONCERNING THE COAL RESOURCES OF OHIO

It has been suggested earlier how a complete inventory of the coal resources of Ohio would provide a basis upon which the systematic and rational development of these resources could proceed, and furnish information that would help to protect the land owner from harmful exploitation. It has been pointed out that such an inventory, in order to present an accurate statement of the facts, must not only indicate the quantity of coal present but the conditions of occurrence and availability and provide information concerning the chemical character and physical constitution of the coal so that discriminating selection is possible in utilizing this resource.

Unfortunately the facilities available to the various Geological Surveys that have operated in Ohio since 1837 have been inadequate to meet the requirements for the type of inventory that has been described and is believed to be desirable. This statement is not intended to belittle the value of the large amount of exceedingly useful information about the occurrence of the various coal beds, their stratigraphic position, and geographic distribution which has been assembled during the past 115 years. The State has acquired at relatively little cost, compared with cost of assembling a similar volume of information today, a great mass of useful information which is available either in published form or in the files of the Division of Geological Survey.

The men to whom the State is indebted for this information worked for small financial return and much of the work represents pure academic inquiry into the stratigraphic problems of the Pennsylvanian or Coal Measures rocks. For many years the limited resources of these Surveys prevented the systematic classification and organization of the material into form suitable for classification and delineation on maps, which is one of the primary requirements for reliable inventory studies. It is only within the last few years that the present Survey has been able to undertake a systematic organization of the data available from the publications, maps, and files, and has been able to start a systematic inventory of the resources contained in the various coal beds of the state.

A PROGRAM OF RESEARCH IN COAL GEOLOGY

It has been the purpose of the rather extended preamble to call attention primarily to the intrinsic value of coal to the State, to the industries within the State, and to the citizens of the State; secondly to indicate the fundamental dependence of the community upon this common but exhaustible energy resource; and, finally to point out that although the availability of the coal supplies as a source of energy is constantly changing, distribution, thickness, and conditions of occurrence are factors of essential continuity and hence represent essentially stable conditions affecting the value of this resource.

In order that the study of the coal resources of the State may proceed in an orderly manner, with various activities and investigations appropriately coordinated and planned, the author speaking here for the Division of Geological Survey presents herewith a detailed "Program of Research and other Activities in Coal Geology" which, if put into action with vigor, would, it is believed, accomplish the desired objective at a relatively rapid rate to the great advantage of the State and its citizens.

This program includes not only the conventional routine activities of a geological survey, but also lists activities in the field of coal petrography (anthracology),* coal geochemistry, studies in the fundamental physical and chemical structure of coal, economic studies, and investigations in the field of applied research. The activities and investigations outlined represent those thought desirable for the Geological Survey, including numerous investigations that should be carried on by cooperating agencies, such as the Geology, Chemistry, Physics, and Engineering departments of the University and by Federal Bureaus. It is hoped that the outline will also prove useful in suggesting fields of research suitable for students of graduate rank and for research institutions and foundations. Following the outline, certain aspects of the program with which there is relatively limited familiarity are explained in more or less detail. A fairly lengthy explanation has been prepared of anthracology, or what is more commonly called coal petrography, since this is one of the less familiar aspects of coal geology.

*A term proposed by J. M. Schopf in 1944 in a privately circulated memorandum.

THE PROGRAM OF RESEARCH AND OTHER ACTIVITIES IN COAL GEOLOGY

General Outline

I. Conventional Geological Activities.
- A. Resources studies.
- B. Structure of the coal measures.
- C. Convergence studies of coal and other beds.
- D. Stratigraphic, sedimentation and classification studies.
- E. Paleontologic and paleobotanical studies.

II. Coal Petrography or Anthracology.

III. Coal Geochemistry.

IV. Studies in the Fundamental Constitution of Coal.

V. Economic Studies of the Coal Industry.

VI. Applied Research (involving mining geology, coal preparation, use of waste material, underground gasification, hydrogenation, mine gas investigations, coking, super-clean fuel, stoker tests, etc.).

Detailed Outline

I. Conventional Geological Activities.

- A. Coal resources studies (1 to 4 preliminary activities; to be undertaken coal bed by coal bed or area by area).
  1. Selection of geographical units of study and mapping. (Areas of 1° longitude by ½° latitude as set up by the O'Neill plan for the coal resources surveys, being the area of 8 conventional quadrangles, is a unit suggested.)
  2. Preparation of standard base maps, scale 1:62,500 with land lines, county, township, city, town and village boundaries, section lines and numbers, quadrangle boundaries, streams, railroads, State and National highways, but not topography, using United State Geological Survey quadrangle maps so far as possible as a basis for construction.
  3. Preparation of suitable "location" sheets to be used in assembling data on base maps and in preparing punched cards.
  4. Development of punched card system of tabulation.
  5. Mapping of coal bed outcrops, accompanied by data on thickness of bed, nature and thickness of partings,

altitude of bed, etc. Identification by location number (index number) for points of observation; recording of data on maps and location sheets. Includes systematic organization of data published or unpublished in the Survey files or available elsewhere.

6. Surveying for drill hole, mine, and outcrop locations and altitude, posting data on topographic base maps and location sheets with index numbers. Includes diamond drill holes, cable-tool, and churn drill holes, and mines of various kinds—shaft, slope, drift, and strip.
7. Collection, filing, and recording of records of drill holes and drafting of graphic logs or preparation of other means of convenient comparison.
8. Delineation of mined-out areas (see VI-A).
9. Transference of location sheet data to punched cards.
10. Preparation of coal resources maps.

B. Structure of the "coal measures" strata.

1. Recording of structure data on location sheets (see I-A-3) : altitude of surface, depth to coal bed, thickness of coal bed, altitude of top or bottom of bed as preferred source of data, etc.
2. Posting of structure data on base map (see I-A, 10) which shows the outcrop lines, mines and mined out areas, drill holes and position of measured coal outcrops, etc.
3. Preparation of punched cards showing structure data as on location sheets, using previously prepared set of punched cards to indicate location, operators, etc. (I-A-9) and adding data on surface altitude and depth and thickness of the coal, using top or bottom of the coal bed as preferred.
4. Drawing of structure contours on map.
5. Preparation of descriptive and interpretative report with suitable consideration of possible relation of structural features to occurrence of oil and gas.

C. Convergence studies of coal and other beds.

1. Delineation by isopach lines of the distribution of variations in interval between selected key beds such

as coal beds, sandstones, and persistent limestones, between key beds and the base of the Pennsylvanian etc., or of variations in thickness of massive sandstones, limestones, or other strata. Use base maps previously prepared upon which datum points have been posted (see I-A, 10).

   a) Preparation of reports pointing out the bearing of the convergence data upon mining operations, or upon problems of stratigraphy or sedimentation etc., with particular consideration of the possible application of the information to problems of roof behavior.

2. Investigation of the nature of regional convergence of selected beds or groups of beds and its possible effect upon coal mining. (Involves the problem of determining how close two beds of mineable thickness may approach each other and remain mineable.)

D. Stratigraphic, sedimentation, and classification studies (largely of an academic and theoretical interest, but with important bearing upon the economic geology of coal resources).

1. Preparation or revision and modernization of generalized stratigraphic section of the Pennsylvanian succession of Ohio based upon regional compilations. ("Regions" to be regarded as areas in each of which there is present essentially the same group of beds, that is, the same cyclic groups, represented in essentially the same way.)
2. Preparation of standard cross-section profiles of the Pennsylvanian strata in Ohio, indicating the nature of transitions from region to region and localities where there are unsettled problems of correlation and their nature.
3. Compilation of a summary statement, which may be gradually assembled, of the major and minor stratigraphic problems of the Pennsylvanian with suggestions in regard to suitable projects for solving these problems.

4. Comprehensive and critical study of basis for Pennsylvanian classification and stratigraphic nomenclature.
   a) Pattern or patterns of sedimentary sequence characteristic of the Pennsylvanian succession in Ohio and immediately adjacent areas in the Appalachian Province, and stratigraphic relationships displayed.
   b) Occurrence and extent of diastrophic unconformities in the Pennsylvanian system in Ohio and immediately adjacent areas.
   c) Significant interruptions in the historical (paleontological) record.
   d) Adjustments between Appalachian and Mid-Continental classifications.
   e) Proposed revisions in classification and nomenclature.
5. Special sedimentation studies of individual cyclical units (cyclothems)* over the Ohio coal field as a possible means of determining the variations in the conditions of coal bed deposition.
6. Special study of the lithology, distribution, and stratigraphic relationships of individual members of the cyclical units such as black "slates," "freshwater" limestones, etc.
7. Systematic study of possible methods of estimating the passage of time during the Pennsylvanian period including:
   a) Summary of existing evidence concerning the duration of the Pennsylvanian period.
   b) Gathering and study of evidence pointing to the time interval between the deposition of successive beds, as indicated by stratigraphic relationships, relative compaction of coal beds, "rolled" coal boulders, "horsebacks," differential subsidence, etc.

*Cyclothem: A name introduced by J. M. Weller that in recent years has often been applied to groups of beds of similar lithologic sequence in the Pennsylvanian system, each group usually containing a coal bed and by definition having at least locally developed, unconformable relations at top and bottom. G. H. C.

c) Time represented by the accumulation of organic matter in individual coal beds.
d) Use of radio active minerals and of other geophysical methods.
e) Experimental procedures.

E. Systematic study of the fauna and flora of the Pennsylvanian period (Largely academic and theoretical with important practical bearings).

1. Preparation of a comprehensive summary or index of the existing faunal record of the Pennsylvanian system of Ohio.
2. Preparation of a comprehensive summary or index of the existing record of the Pennsylvanian flora of Ohio.
3. Special studies in various fields of the macro- and microfauna and flora of Ohio including coal ball studies and studies in pure paleontology and paleobotany including fusulinids, ostracods, plant spores, lamellibranchs, to which considerable study has been given in other coal fields.
4. Preparation of lists of guide fossils and tabulations of time ranges of species and genera useful for correlation and identification.
5. Study of ecology of individual coal beds to determine the possibility of systematic variations in the character of the vegetation during the accumulation of plant debris.
6. Study of the distribution and occurrence of marine, brackish water and fresh water life in the cyclical units, particularly the relation of coal beds and marine deposits.

II. Coal Petrography or Anthracology (Study of coal as a rock substance) (Fig. 6).

A. The banded ingredient composition of Ohio coals from columns or drill cores.

1. Megascopically prepared bed profiles.
2. Bed profiles based upon thin sections.
3. Bed profiles based upon microscopically examined polished surfaces.

B. Petrographic analysis of coal bed columns or cores.

1. Rough analysis based upon megascopic bed profiles using columns or cores.

2. Detailed analysis based upon microscopic examination of thin sections and/or of polished surfaces in terms of *a*) banded ingredients including mineral matter and *b*) humic material (vitrain and vitrinite; "proto bituminous" components (exines, cuticle, and other waxes and resins, etc.); fusain: opaque matter other than fusain; and mineral matter of various kinds.

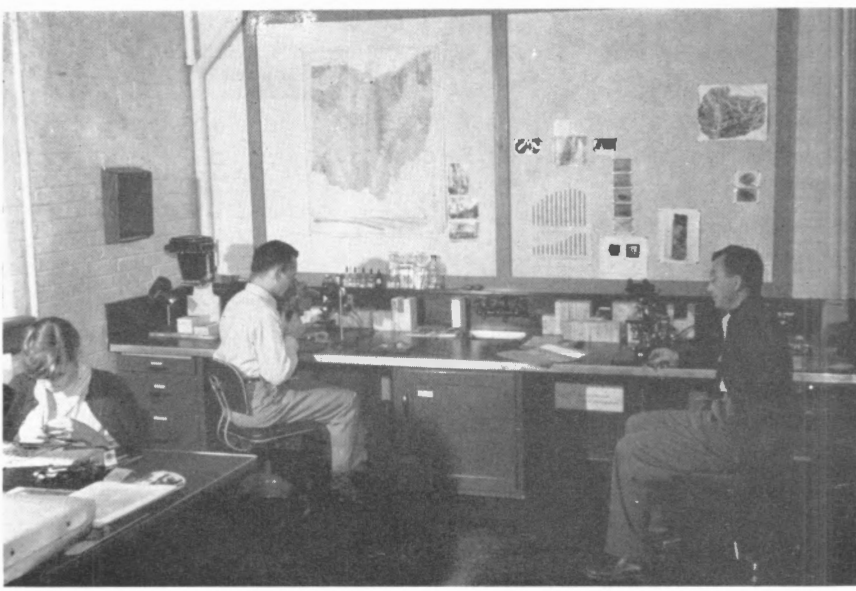


FIG. 6. Anthracology or Coal Petrography laboratory of the U. S. Geological Survey, Ohio State University, Columbus.

C. Petrographic analysis of broken coals.

1. Analysis of typical size varieties of broken coal from mines for which column studies have been made, using either the particle count method or integrating stage method.

2. Study of results of broken coal analysis in comparison with profile analysis with interpretations.

3. Study of the effect of various mining processes on the distribution of ingredients in prepared coal.
4. Investigation of the relative capacity of various preparation processes for producing pure ingredients.

D. Investigation of the properties of the banded ingredients.

1. Chemical analyses of hand picked samples.
    a) Study of variations resulting from differences in rank.
2. Physical properties including variations due to difference in rank: specific gravity, hardness, conductivity, porosity (including ultra-fine pore space), permeability, reflectivity and other effects on light, etc.
3. Coking properties (British Standards coking tests, agglutinating tests, behavior under conditions of high temperature as determined by microscopic examination, etc.).

E. Hydrogenation capacity of the various ingredients.

a) Special study of opaque matter or durain (splint coal).

F. Study of the mineral matter present in Ohio coals.

1. Kind and amount of minerals present.
2. Distribution of minerals with respect to kind of banded ingredient.
3. Effect of preparation on the mineral content and possibility of improved elimination.

G. Systematic study of coal metamorphism (based mainly on study of vitrain).

1. Investigation of the applicability of Hilt's law to Ohio Coals: the relation between depth of burial and rank of coal determined by analyses of vitrain samples.
2. Investigation of regional variation in the rank of Ohio coals based mainly upon analyses of vitrain.
3. Determination of variations in the amount of ultra-fine pore space in vitrains of different rank from Ohio coal beds.

4. Correlative study of pore space in sandstones associated with coal beds used in previous tests (see also IV-A, 1).
5. Correlative investigation similar to those used above (D, 2), of physical properties of vitrain samples of different rank.

FIG. 7. Coal Chemistry Laboratory of the Engineering Experiment Station, Ohio State University, Columbus.

III. Coal geochemistry.

A. Conventional Chemical Tests: (Fig. 7).

1. Sampling and analysis of representative coal beds of Ohio using standard analytical procedure with items reported as indicated under No. 3 below. It seems probable that reliable generalizations in regard to the distribution of variations in the various items of the analyses can be obtained by sampling no more than 10 mines for each bed practically coextensive

with the coal field. Coal beds with more restricted distribution will probably require fewer samples. In general each mine should be sampled at three places as widely spaced as possible in each mine. The composite samples are made by combining in correctly weighted proportions the three or four face samples.

2. Sampling of banded ingredients and other special sampling (see Sec. II).
3. Coal analysis by a selected chemical laboratory following standard procedure, with an appropriate number of check analyses run by special arrangement with the U. S. Bureau of Mines laboratory at Pittsburgh.
   a) Proximate analyses to be reported on the following bases using a punch card system where possible:
   (1) As received, (2) moisture free, (3) ash and moisture free, (4) moist, mineral matter free, and (5) dry, mineral matter free (unit coal basis). Most if not all the values listed can be calculated mechanically from the "air dry" form of analysis and the "as received" moisture value.
   b) Ultimate items to be reported on the following bases for the composite samples:
   (1) As received, (2) moisture free, and (3) ash and moisture free.
   c) The following items to be reported with the ultimate analysis:
   (1) Forms of sulphur (organic, sulphate, pyritic).
   (2) Ash fusion points.
   (3) British Standards swelling tests on coal.
4. Plotting of values on base maps and delineation of distribution of variations in moisture, ash, and of fixed carbon on a moisture and ash-free basis (carbon ratio).
5. Plotting and mapping of distribution of variations in unit B.t.u.
6. Plotting and mapping of distribution of variations in rank (rank index or moist, mineral matter-free B.t.u.).

7. Analytical determinations on vitrain (see II-G, 2 and III-A, 2) and on other separable constituents of Ohio coals.
8. Investigation of the possibility of using chemical analytical and testing procedure for determining the ingredient content of Ohio coals, or of the content of humic (vitrain and "vitrinite"), proto-bituminous ("extinite," "cutinite," "resinite" etc.,) and carbonized (fusain, durain, "micrinite" etc.,) components.

IV. Studies in the Fundamental Constitution of Coal.

A. Geophysical field.

1. Application of the electron microscopy to the investigation of the fundamental constitution of coal.
2. Investigation of the ultra-fine structure of coal.
   a) Colloidal structure of coal and its banded ingredients and plant fossil components.
   b) Study of the internal surfaces of coal.
   c) Changes in the ultra-fine structure with changes in rank.
3. Constitution of coal as revealed by infra-red spectra.
4. Constitution of coal as revealed by ultra-violet spectra.
5. X-ray studies of the physical constitution of coal and the banded ingredients directed especially toward the forms of carbon in coal.

B. Physio-chemical field.

1. Thermal studies of coal and its banded ingredients and plant fossil components.

V. Economic Studies of the Coal Industry.

A. Annual review of production and distribution of Ohio coals with interpretations with respect to related industries, competitive markets, and competitive fuels, etc.
B. Periodic studies of the Ohio coal market area.
C. Fuel situation in the utility field in Ohio.
D. Economics of strip mining and land reclamation.
E. Coal brasses as a source of sulphur in Ohio.

VI. Applied Research and Related Activities.

A. Mining problems having a geological bearing.

1. Maintenance of records of mines and mining operations in Ohio.

a) Location of shafts or other openings to underground deposits of coal, and of strip mines (location of tipple);
b) Note railroad, highway, and dock facilities;
c) Altitude of surface landing for shafts of slope mines;
d) Altitude of bottom of coal bed for drift mines;
e) Altitude of base of coal bed at some specified located position in strip pit;
f) Thickness of coal bed at foot of shaft bottom of slope, opening of drift, or where altitude is measured in strip mine;
g) Important irregularities, character and frequency;
h) Usual thickness of coal in mine, maximum and minimum thicknesses with frequency of each;
i) Number, thickness, position, and persistence of partings;
j) Character of roof and character of floor;
k) Production and capacity and annual record of production;
l) Dates: when opened, when abandoned, and when idle;
m) Extent of mined out area, particularly at the time abandoned;
n) Name of operator with changes and dates indicated.

The foregoing data to be entered on special mine record sheets or on appropriate maps.

2. Geological conditions contributing to falls of roof, and analysis of geological factors involved.
3. Unusual structural conditions in the Pennsylvanian strata of Ohio affecting mining operations other than roof conditions.

4. Occurrence and distribution of shale partings in Ohio coal beds and their effect on mining.
5. Extent of strippable resources, particularly for small operations and for less well known beds.
6. Strippable resources remaining in abandoned operations.
7. Sandstone distribution and its effect on strip mining.
8. Available but largely undeveloped deep coal resources of Ohio.
9. Geological factors affecting the occurrence of methane and other gases in coal mines in Ohio.

B. Coal preparation investigations.

1. Systematic study of the petrographic composition of the products from standard coal preparation plants (see II-C, 1-4).
2. Investigation of possibility of controlling coal type in prepared coals by coal petrography.
3. Investigation of possibility of the production of ultra-pure products for special uses such as gas turbines, carbon electrodes, hydrogenation, etc.
4. Possible uses of high concentrations of fusain and durain.
5. Possible uses of high concentrations of proto-bituminous components (spores, cuticles, resins, etc.).

C. Underground gasification studies.

D. Hydrogenation of Ohio coals.

E. Studies relating to sulphur in Ohio coals.

1. Investigation of occurrence, distribution, and availability of coal brasses as a source of sulphur.
2. Investigations of methods of improving the processes of sulphur removal from Ohio coals.

F. Coking investigations.

1. Possibility of utilizing Ohio coal in whole or in part in the manufacture of metallurgical coke.

COMMENTS IN EXPLANATION OF THE "OUTLINE OF A PROGRAM OF COAL RESEARCH"

INTRODUCTION

The following comments in explanation of certain of the topics and sub-topics listed in the preceding outline of activities in the field of coal geology appropriate for the Ohio Division of Geological Survey have been prepared to give the lay reader a better understanding of the less familiar aspects of coal geology. The more conventional fields of coal geology represented by coal bed mapping, coal resources studies, the determination of the stratigraphic position of the various coal beds, and the chemical characteristics of the coals in terms of the items of the commercial types of analysis represent what is commonly understood as coal geology. Less familiarity exists with respect to many other phases of coal geology, particularly with the study of coal microscopically and the physical make-up of the coal bed and with the geochemical and geophysical aspects of coal geology. Most of these items are explained in some detail.

The sections in the paragraphs to follow are arranged and numbered the same as in the "Outline" so that reference from the "Outline" to the "Comments" is readily possible and more definite references are occasionally inserted in the text.

I. CONVENTIONAL GEOLOGICAL ACTIVITIES

Two primary purposes determine the character of the activities in coal geology outlined under this heading: first, to provide geological information useful to the coal mining industry in the exploration for additional supplies, in the development and operation of coal mining properties, and in the preparation of coal for various types of utilization; second, to make possible from time to time, as the amount of information increases, comprehensive and dependable inventories of the coal resources of the State.

The close relationship between geology and the coal mining industry is in general not realized, hence it is one of the functions of the State Geological Survey to explain and demonstrate the nature and importance of this relationship, so that full advantages of the facilities of the Survey may be taken by those interested in the development of this resource.

The coal resources inventory. The second main objective, the determination of the quantity of the coal in the reserve supply, is a clear cut responsibility of the Geological Survey, since it is that Division of the State government concerned with the exploration, descriptions, and delineation of the mineral resources of the State. A good share of the prosperity of the State resides in its supply of workable coal, hence it behooves the State through its appropriate agencies to conduct periodic inventories, based upon the best information available, of its coal resources, in order that these supplies, or any important part of them, which have often been regarded as inexhaustible, may not suddenly be found precariously close to exhaustion. This concept is, as suggested, one that applies not merely to the coal supply as a whole, but to an even greater extent to those supplies of coal having unusually desirable qualities or having exceptional ease of accessibility or both, and therefore of exceptional competitive importance, concerning the possible imminent exhaustion of which the State and its citizens should be informed.

In general coal mining operations in Ohio have been carried on at a relatively shallow depth, many underground operations having been developed from drift openings, and, as has been pointed out, during the past ten to fifteen years particularly an increasing proportion of recovery has been effected by open-cut operations. Such mining proceeds at an exceptionally rapid rate with respect to the reserves of such coal. Carefully conducted inventories will reveal when these supplies of strippable coal are approaching exhaustion or to a precariously narrow limitation in quantity, thereby indicating the need for extensive exploration in those parts of the coal field where workable beds lie at depths 500 feet or more below drainage level.

Stratigraphic studies. The conventional geological activities listed in this outline (Part I) should include stratigraphic studies adequate to determine the exact position of any coal bed in the Pennsylvanian system (Plate I) and its relative position with respect to other coal beds and to key strata such as prominent and relatively continuous limestone, sandstone, and clays. Such information would also aid in the correct correlation of coal beds in Ohio with those in adjacent states of Kentucky, West Virginia, and Pennsylvania. Precise correlations of this kind are often of considerable importance in the coal trade.

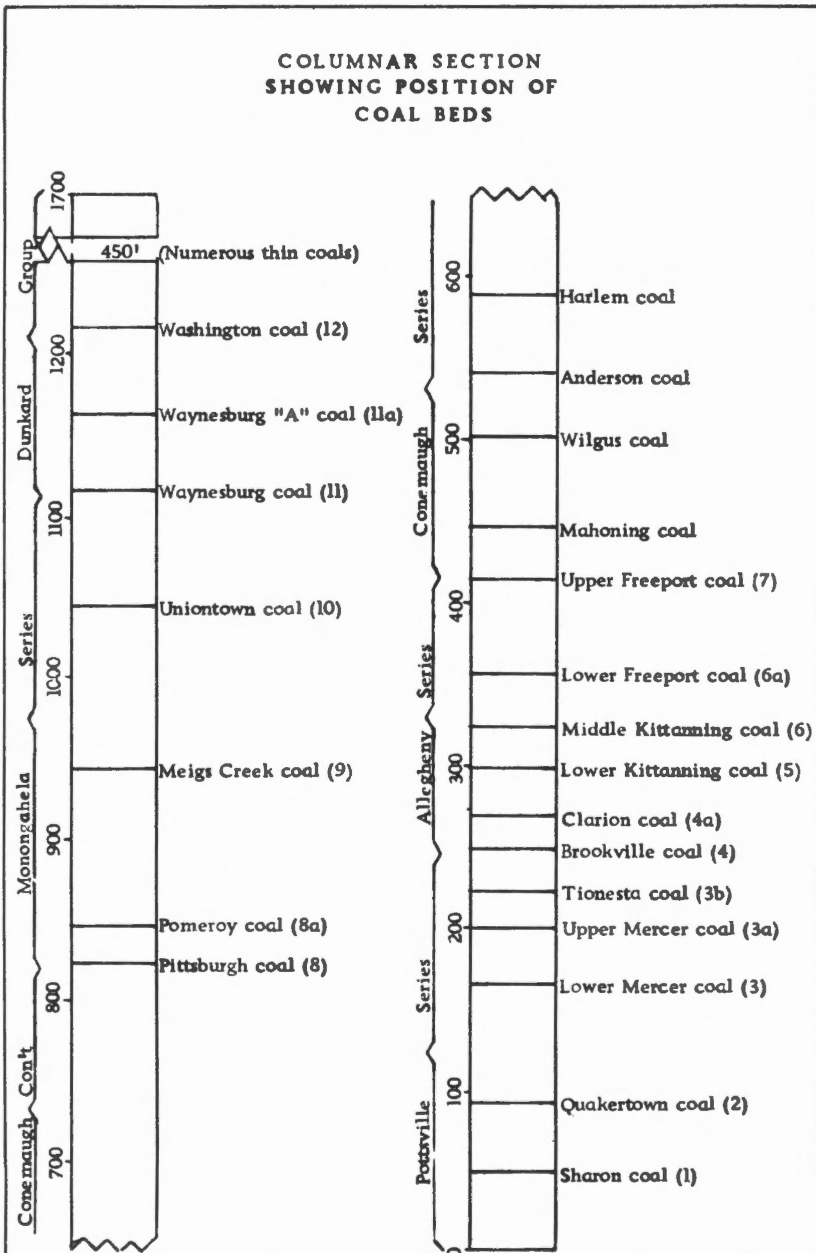
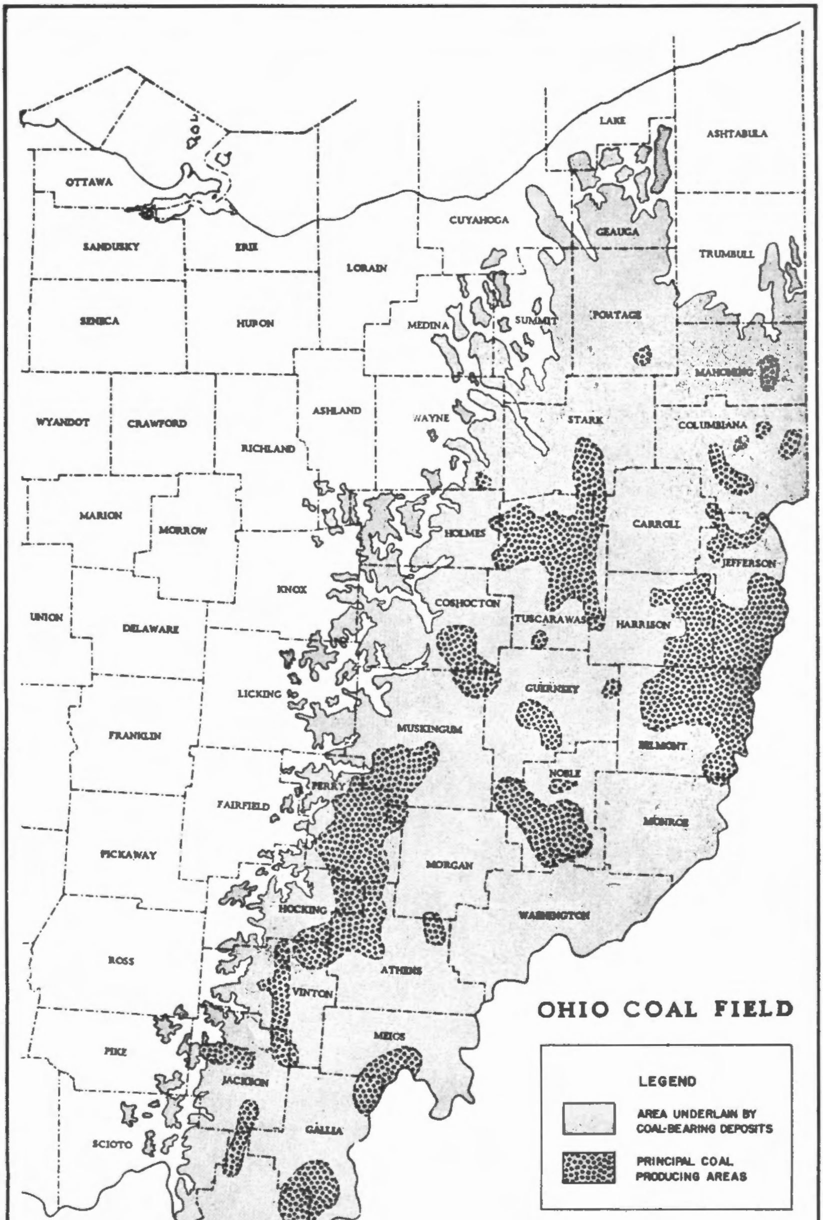

COLUMNAR SECTION
SHOWING POSITION OF
COAL BEDS
Dunkard Group
Monongahela Series
Conemaugh Con't
1700
1200
1100
1000
900
800
700
450'
(Numerous thin coals)
Washington coal (12)
Waynesburg "A" coal (11a)
Waynesburg coal (11)
Uniontown coal (10)
Meigs Creek coal (9)
Pomeroy coal (8a)
Pittsburgh coal (8)
Conemaugh Series
Allegheny Series
Pottsville Series
600
500
400
300
200
100
0
Harlem coal
Anderson coal
Wilgus coal
Mahoning coal
Upper Freeport coal (7)
Lower Freeport coal (6a)
Middle Kittanning coal (6)
Lower Kittanning coal (5)
Clarion coal (4a)
Brookville coal (4)
Tionesta coal (3b)
Upper Mercer coal (3a)
Lower Mercer coal (3)
Quakertown coal (2)
Sharon coal (1)

PLATE I



OHIO COAL FIELD

PLATE II

Coal bed mapping. The attainment of the objectives of routine geological activities requires the systematic and precise mapping (Part I-A-5) of the outcrops of the various coal beds in those regions of the State where such beds lie above drainage, and in the continuation of the mapping below drainage level by the use of drilling data. Variations in the "lay" or structure of the coal are shown by coal-bed structure maps. Mapping of coal bed information in order to be complete includes also the detailed recording of the characteristics of each bed as observed in outcrop, in mines, and in the cores of drill holes. This procedure also involves recording of measured thicknesses, of the occurrence, distribution, character, and quantity of the mineral impurities, and of the nature of bedded irregularities such as "rolls," "horsebacks," "white-top," and erosional "cut-outs." The characteristics of the roof and floor should be carefully noted and maps prepared showing distribution of variations in these characteristics.

Engineering data. Engineering data must also be assembled concerning the altitude of the index strata, including coal beds, the precise location and elevation of points of reference such as outcrops, drill holes, and mines, measurements of thickness of strata and of intervals between key layers, and the collection of drilling data, etc. (Part I-A, 5). Because the topographic maps of Ohio quadrangles were generally completed many years ago, temporary bench marks have been largely obliterated or rendered useless by years of road grading and other surface changes. Hence in order that structure maps may be reasonably accurate fairly numerous critical points will have to be tied in to permanent bench marks that show no evidence of having been disturbed. The altitude of intermediate points of less importance can probably be determined with sufficient accuracy by hand level or carefully checked barometer or altimeter determinations.

Structure studies. Structure maps (Part I-B) of coal beds, in some states at least, reveal structural irregularities which, depending upon the extent to which they involve strata lying far below the bed mapped, may be indicative of structural conditions favorable to oil and gas accumulation. Mapping of coal bed structure on a relatively large scale with small contour interval, might well result in the discovery of places where a suggestion of favorable structure is indicated in beds which lie far above the oil producing horizon or horizons.

Convergence maps. Convergence maps (Part I-C) may be occasionally required in evaluating coal deposits and in planning coal mining operations. For example, the mineability of two coal beds may vary with the interval that separates them, particularly if the variations are such as to produce areas of close approach. The effectiveness of roof bolting may vary considerably with the variation in the interval between the coal bed and its cap rock. Convergence maps are also useful in indicating the extent and distribution of sandstones having channel-like cross section lying at various positions with respect to underlying coal beds.

Academic studies. In connection with more or less routine geological and engineering activities related to coal resources studies, other investigations of a more academic character are commonly made (Part I-D). These may concern the identification and mapping or "key" beds other than the coal beds, such as lithologically distinctive limestones, sandstones, shales, or clays, some of which may have economic value besides being useful as "key" or reference beds in structure and stratigraphic studies. Academic studies may provide fundamental bases for interpreting the geological history of the coal beds and involve study of the animal and plant fossil record.

Such academic investigations may include studies of various kinds in Pennsylvanian classification, correlation, and sedimentation, and with studies that have to do with the measurement of the time represented by the Pennsylvanian system or by its constituent units including the coal beds. The evaluation of the time element is an exceedingly important consideration in the solution of problems relating to coal accumulation and coal metamorphism, but for the present at least, it can be most appropriately approached as an academic problem. Since studies in classification and sedimentation also have a somewhat remote bearing on the economic geology of coal, so that the common emphasis placed on these aspects of coal geology in academic circles favors graduate investigations in these fields. Such academic research is to be encouraged, because occasionally the results obtained prove of considerable practical value, an outcome that it may often not be possible to foresee. Special encouragement should, however, be given to those desiring to investigate problems in coal geology having a definite economic bearing.

Fossil plants and animals. The study of the fauna and flora of the Pennsylvanian period (Part I-E) is likely, under academic direction, to consist mainly of detailed investigations in the fields of zoology and botany or in the geological fields of stratigraphy and correlation. Certain aspects of practical importance may be pointed out: although identification and correlation of coal beds in Ohio in general have been fairly well established, in dealing with coal cores recovered from drill holes, particularly in the central part of the coal field, it is important to have evidence, such as would be supplied by index fossils, as a basis for correlation and identification. There is also some value in being able to correlate Ohio coal beds with those present in other fields with which there is no continuity, such as the fields of the Interior Provinces. Continued investigation of fossil spores and possibly other microflora in coal beds and other Pennsylvanian strata may make possible better interbasin correlation.

The amount of information available on the fossil flora and fauna of the Pennsylvanian system is considerable, and a summary list, which might be compiled with the aid of some punched-card system of tabulation, is a desirable objective.

Several possible lines of research in paleontology and paleobotany are suggested in the outline and these suggestions by no means exhaust the possibilities. Improvement in knowledge in many of these fields is, at least academically, desirable and would probably lead to results of direct or indirect practical significance.

II. Coal Petrography or Anthracology

Coal petrography, or what will be called by the new term *anthracology**, is a relatively new branch of geology dealing with the physical constitution of coal in much the same way that petrography deals with the mineral composition of rocks. Investigations in this field of coal geology, particularly in the last two generations, have greatly widened the understanding of the nature of coal and have supplied much information about the constituents, components, and ingredients of this fossil fuel. (In this discussion of the items of the "Outline" appearing under the heading Coal Petrography, the term *constituent* is general in its application and includes both coal *components* and banded *ingredients*.) It is the purpose of these comments to explain some of the more commonly used terms and the more common methods of investigation, and to point out some of the benefits of a better understanding of the physical constitution of coal.

*A term proposed by J. M. Schopf in 1944 in a privately circulated memorandum.

At the risk of over-simplification it may be said that anthracology is concerned with the physical variations in coal which make it possible to classify coal material by type. Variations in rank resulting from the inequal but progressive severity of the geological environment characterize coal of all types. These rank differences can be arranged systematically producing the familiar coal-rank series extending from brown coal, through lignite, subbituminous, and various ranks of bituminous coal to anthracite. Variations in type result from the differences at the time of its burial in the character of the material from which the coal was formed, that is, for example, whether the initial material was wood or bark, waxes or resins, charcoal-like material, etc., to mention a few possibilities of variation.

Coal Type

Coal ingredients. The phrase "Coal petrography" is a product of the proposal by Stopes[13] in 1919 to recognize the four megascopic banded ingredients of coal: vitrain, clarain, durain, and fusain, and of her approach to the study and description of the banded bituminous coals, more or less after the method used in igneous rock petrology. The banded ingredients were regarded as analagous to rock types, and the smaller coal components composing the ingredients Stopes eventually designated as *Macerals*, simulating the term mineral.

Since the ingredients as recognized by Stopes are of great importance in the type description of coal a brief explanation of each ingredient follows:

1. Vitrain: Bright, glossy bands of unstriated coal, which microscopically is found to represent the coalified woody (or bark) tissue of plants. Vitrain bands vary in width from several inches to microscopic width. (Fig. 3.)
2. Clarain: Clarain is composed of varying amounts of fine vitrain (micro-vitrain) up to nearly 100 per cent and fragmentary material of various kinds. The brightness of clarain in general depends upon the amount of fine vitrain present, and accordingly varies from very bright to fairly dull, but the bright clarain differs from vitrain in being striated.
3. Durain: This is predominantly dull coal, and can usually be distinguished from dull clarain only in that durain is

opaque when viewed microscopically in thin sections, whereas clarain (and vitrain) is translucent. (Transitional varieties of Nos. 3 and 4 may be designated duro-clarain and claro-durain depending on whether they are predominantly translucent or predominantly opaque.)

4. Fusain: "Mineral charcoal," in lenses, bands, and fragments.

These are the predominating megascopically recognizable varieties of coal material found characteristically as bands in such bituminous coal as is found in coal beds in Ohio. Singly or in combinations they make up the more common types of coal. In combination they produce the commonly recognized standard type of "common banded bituminous coal" (Fig. 4), whereas beds of coal composed predominantly of one variety of coal like splint coal (durain) and cannel (clarain or durain) are characteristically unbanded. The main source of the banded structure of coal resides in the irregularly spaced bands of vitrain of variable thickness.

More or less opposed to this petrographic concept of the constitution of coal are the ideas of Thiessen[14] whose point of view was more naturalistic, since he regarded coal as a special variety of fossil plant material, and, by viewing thin sections prepared from the coal by the aid of the microscope, was able to correlate various types of coal with specific kinds of plant material. There is therefore a "botanical" as well as a "petrographic" aspect to anthracology, which makes even more desirable the use of the more generalized less specifically connotative term as a name for this field of coal geology.

Those who follow the Thiessen concepts of the constitution of coal recognize three main kinds of coal material or types of coal. That material which is derived from wood or bark, as can be demonstrated microscopically, is called anthraxylon (coalified wood); fusain is "mineral charcoal" as in the case of the Stopes classification; the balance of the material, being composed of fine particles or thin shreds, is designated as "attritus" and it may be either "translucent" attritus or "opaque" attritus. It is obvious that the use of the miscroscope is essential for the differentiation of coals in following the method established by Thiessen and as employed by the U. S. Bureau of Mines, whereas the Stopes method is primarily for use without the microscope. This method is used very largely in Europe and microscopic determinations if made are usually made from polished surfaces rather than thin sections of coal. At the present time this is the main difference between American and European methods of anthracology.

Correlation between the concepts and terminologies of the Stopes and Thiessen systems of coal description are fairly well agreed upon. It is generally understood that the larger bands of anthraxylon are vitrain. (Fig. 4.) Clarain consist of varying amounts of fine vitrain (micro-vitrain), or fine anthraxylon, and other heterogeneous, fine, more or less granular translucent material. The distinguishing characteristic of durain is its dullness in hand specimen and opacity in thin sections. Thin sections of splint coals are predominantly opaque under the microscope, hence the name durain and splint are commonly regarded as essentially synonymous. Some clarain is also relatively dull in hand specimens and without the use of thin sections it is impossible to determine whether or not such coal is opaque, and therefore splint coal, or is a variety of clarain. Fusain is similar in both systems of description.

The use of thin sections is unsuitable for coals of high rank. Anthracite coal cannot be ground sufficiently thin to be transparent, and transparent sections were difficult to make of even the higher rank bituminous coals. Since such high rank coals are common in western Europe, and since it was demonstrated by thin sections of lower rank coals that microscopic examination of coal was essential to an understanding of its physical constitution, an elaborate technique for the study of polished surfaces of coal has been developed by coal geologists in western Europe[15]. With this technique the results are similar to those obtained by the use of thin sections, with the added advantages that the method is applicable to coals of all ranks from lignite to anthracite and such polished surfaces can be of fairly large size and can be quickly prepared. However, there is difficulty in identifying opaque material in polished surfaces and identification of many of the microscopic components of the coal is accomplished with greater certainty with thin sections. Both techniques are useful and neither should be neglected.

Bed profiles. Classification of the varieties of coal on the basis of megascopic differences provides a useful means of description in terms of the four banded ingredients. It is possible to prepare detailed profiles of the bed (Part II-A and B), using freshly broken or polished surfaces of coal bed columns or cores. Such profiles reveal the proportion of the ingredients, their distribution in the bed, and their width. This information is important in determining how the coal will respond to the mining and preparation

Photo by U. S. Bureau of Mines

FIG. 8. Microphotograph of a band of vitrain showing embedded resinous matter.

processes and its adaptability to various types of utilization. Such examination and analysis provide only an approximate picture of the constitution of the coal; for accurate and detailed description of the physical constitution of the coal a microscopic analysis is necessary.

Microscopic analysis of coal beds. In order to understand and describe accurately the physical constitution of coal, microscopic examination of the megascopic ingredients is necessary using thin sections or polished surfaces or both. Such microscopic study will reveal considerable variability even in such uniform appearing material as vitrain. Some vitrain will be found to contain resinous (Fig. 8) material in considerable abundance, and waxy inclusions will be found in other vitrain bands.

The heterogeneity of clarain is particularly important, because banded bituminous coals commonly are composed of 70 to 75 per cent of clarain and there is considerable range of variation. Some clarain consists predominantly of fine or micro-vitrain shreds. This is the character of bright clarain. (Fig. 9.) Other clarain consists of a great variety of fine organic material and mineral matter. In some clarains the proportion of waxy entities represented by spore coats and leaf and stem cuticles may be relatively large. Resinous bodies compose a considerable part of the matrix of some coals. Dull clarains may contain minor amounts of opaque matter thus grading into durain.

The determination of the occurrence and character of mineral matter in coal is also one of the purposes of microscopic anthracology. The more common minerals found in coal are clay, calcite, pyrite, and kaolinite. The manner of their occurrence is of great importance in connection with the cleaning of coal.

Using the information supplied by microscopic investigations the physical constitution of the coal can be described in more detail than is possible on the basis of the banded ingredients alone, particularly with respect to the composition of the ingredient clarain. Such information is essential to an understanding of the effect of preparation in altering the type of coal, as explained in the following section on physical analysis of broken coal.

Anthracology of broken coal. Because the banded ingredients in banded bituminous coals vary considerable in physical characteristics such as hardness, brittleness, and other properties affecting breakage, the mining and preparation processes from start to finish tend to modify the proportions present in prepared coal as compared with the initial proportions in the bed (Part II-C). To understand the effect of these processes upon the coal in the bed it is necessary first to determine the profile composition, as explained in the previous section, and then to obtain petrographic analyses of the broken coal as it is produced by the various processes of sizing and cleaning. Variations in hardness, and variations in specific gravity make possible two kinds of concentration or separation.

Photo by U. S. Bureau of Mines

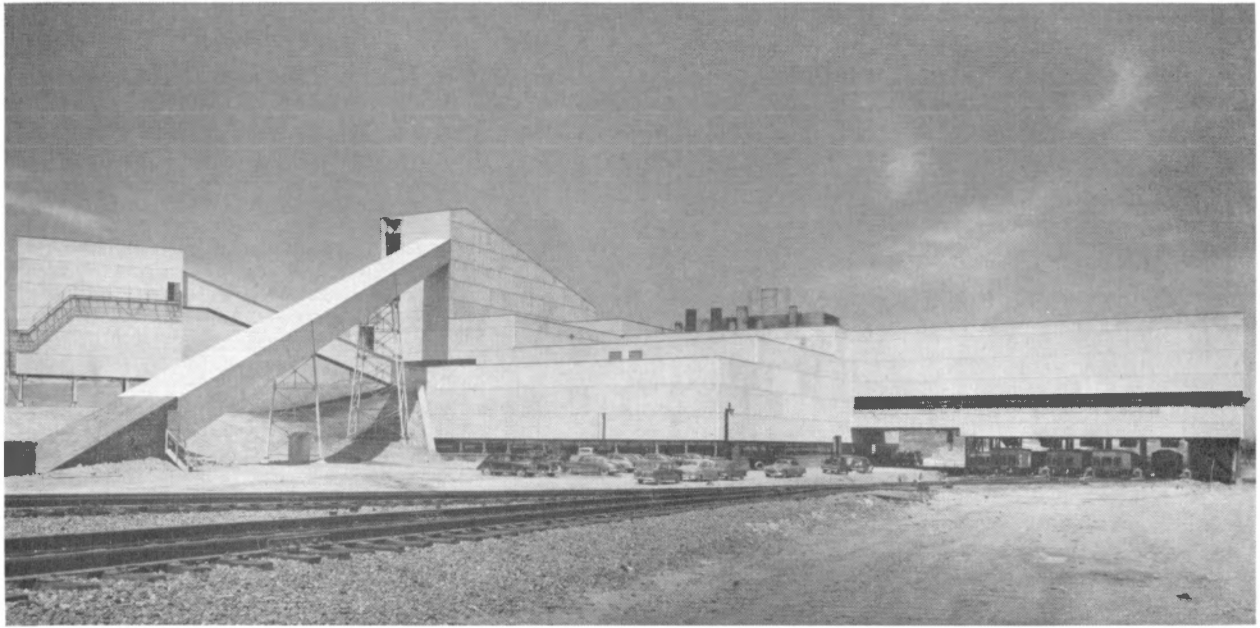
FIG. 9. A thin section of Sharon coal bed, Jackson County, Ohio, showing thin banded attrital type (clarain) coal.

The analyses of broken coal in terms of the banded ingredients provide information concerning the effects of the preparation and cleaning processes other than the effects upon ash or mineral matter content. (Fig. 10.) Such analyses demonstrate the modifications in the type classification brought about in the handling of the coal. Thus it will commonly be found that certain grades of coal contain a very much larger amount of fusain than is characteristic of the whole coal bed. In other sizes there may be a concentration of vitrain. Or concentrations may be a matter of specific gravity rather than size. The possibility of obtaining coal of a desired type from a bed which as a whole is of a different type requires an understanding of the nature of coal type and how it can be controlled. This might be regarded as the ultimate practical objective of anthracology.

Coal Rank

Coal metamorphism. It was stated near the beginning of this section that variations in rank reflect the unequal severity of the geological environment (Part II-G.) The primary requirement for the start of the coalification process in an accumulation of plant material is burial, after which at least up to a certain degree of alteration, a fairly definite relationship exists between degree of metamorphism or rank and depth of burial, according to a law known as Hilt's Law. (According to "Coal" by E. S. Moore, p. 177: "In American seams, out of 34 investigated, 29 showed an average decrease (in volatile matter content) of 0.38 per cent per 100 feet descent.") In general there is a progressive decrease with depth, but the rate seems to be very uneven on the basis of data usually used to measure rank. In regions where vertical or hydrostatic pressure is reinforced by tangential or lateral pressure, as is the case where coal measures lie in areas of regional deformation, coalification and metamorphism proceed much farther, and, if heat is involved, may continue until the coal becomes anthracite or even to complete alteration into graphite.

The standard bases for differentiation of coal by rank are predominantly those determined in the chemical laboratory, heat value, volatile content, carbon, hydrogen, and/or oxygen content, coking properties, individually or in various sorts of combinations. At the present time in this country the standard method of classifying coals by rank is by the use of criteria based upon volatile matter and moisture content, heat value, and coking and weather-



Courtesy of Hanna Coal Company

FIG. 10. Coal preparation plant of Hanna Coal Company at Georgetown, Harrison County, Ohio. This plant, the largest in the bituminous coal industry, costing more than $5,000,000, has a capacity of 1,500 tons of raw coal input per hour. Coal from several mines is processed in this plant at the average rate of 1275 tons of clean coal per hour which is loaded for distribution on five tracks served by two railroads. In a modern cleaning plant such as this, coal is upgraded in heat value several thousand BTU'S per pound through the removal of 10 to 20 percent of the input, and the ash is reduced to 7 or 8 per cent or less.

ing properties. This subject will receive further consideration in the Comments on Coal Geochemistry (III to follow).

Physical measurement of rank differences. The early physical effects of metamorphism are probably capable of more precise measurement in coal than in associated strata. However, it is important to apply criteria to the same general type of coal in order to obtain measurements suitable for comparing one coal with another. In general the less heterogeneous the composition of a coal type the better can precise measurements be duplicated, therefore measurements made on vitrain are regarded as preferable to those made on the whole coal or other banded ingredients or components.

Measurements of the extent of reflectance and of the polarization of reflected light have been occasionally used as a means of measuring rank. Since such properties are probably related to the internal structure of the "coal molecule" they are fundamentally reliable to the extent that they are accurately determined. Although it has generally been thought that metamorphism of coal proceeds continuously and without interruption through the coal series, Seyler[16] and some others have presented evidence which is interpreted as indicative of a step-wise progression advancing in a series of nine steps which if factual would permit the definite differentiation of successive ranks. Agreement in this interpretation is not universal.

Other physical properties known to vary more or less progressively with the advancing rank of coal are x-ray properties, hardness, and probably to some extent conductivity. None of these properties have been investigated sufficiently to establish the extent of their usefulness and hence provide suitable field for exploratory research.

III. Coal Geochemistry

Since coal represents an accumulation of organic material which is very susceptible to modification in the geological environment, geologists have for a long time pointed to the importance of coal as a gauge for measuring the extent of dynamic influences. David White wrote in 1913:[17] "The writer has frequently urged that coal, on account of sensitive reactions to dynamic influences, offers a most delicate medium for the observation of earth metamorphism —one that is applicable in regions whose dynamic phenomena are below the scale range of ordinary metamorphic criteria or methods. At present, however, this most sensitive scale lacks calibration."

The most readily available chemical criteria for calibration of the geological effects are data obtained by methods for evaluating coal for use (Part III). Elementary or ultimate analysis of coal was, of course, a natural procedure of the analytical chemist, but the application of the information thus obtained to problems of coal utilization was not readily made. As early as 1844, Johnson[18] made use of the volatile matter fixed carbon ratio in classifying American coals for the United States Government. Nearly 100 years ago Rogers[19] observed that "the distinctive properties of different kinds of coal are determined mainly, though not altogether, by the relative proportions of solid carbon and volatile matter which have been severally retained. Coals are therefore styled bituminous, semi-bituminous, or anthracitic—that is purely carbonaceous—as they possess respectively a full supply, half a share and no trace at all of bitumen." This idea has won general acceptance in spite of the general absence of true bitumen in coal, and the proximate analysis, which usually includes besides volatile matter and fixed carbon determinations, determination for ash, moisture, sulphur, and heat value, has come into wide use in the evaluation of coal, the methods of analysis becoming standardized about 1913.

Because the conventional commercial forms of coal analysis have some scientific and great practical usefulness and the proximate analyses, at least, are relatively simple of determination, chemical studies of coal have consisted largely of the determination of proximate values based upon standard face samples collected and sealed in the mine against loss of moisture and volatile matter while on the way to the laboratory. Commonly ultimate analyses are made from several face samples from the same mine proportionately composited in the laboratory, so that the number of ultimate analyses is in the order of 1/3 to 1/5 the number of proximate analyses, but there is usually one ultimate analysis available for each mine sampled. For classification purposes it is generally thought necessary to use averages, based upon determinations in good accord, of at least two face samples from the same mine or closely adjacent localities.

There appears to be no question that organic material initially different in character contributed to the coal forming material. It is of interest to the geologist to know the nature of the steps and the stages at which such steps are taken whereby one kind of organic material as distinguished from another progresses toward the common goal. Anthracologic evidence indicates that coalification is not a uniformly progressive operation irrespective of the kind of organic material, some ingredients or components progressing in coalification more rapidly than others. Rank, therefore, as determined by proximate analysis of a standard face sample is an approximate average for the bed at the place sampled. Analyses of individual ingredients or components of the coal on the same basis might provide bases for quite different classifications, as previously pointed out. Between some ingredients or components the difference would be considerable.

Whether or not chemistry or physical methods will eventually arrive at an absolute method for calibrating the rank of the various types of coal remains to be determined, but such an achievement is greatly desired. This may be accomplished by x-ray or other physical methods, thus providing a clearer picture of the nature of molecular structure of coal and of the progressive changes in this structure brought about by the coalification process.

Chemical information concerning Ohio coals. The number of analyses of Ohio coals based upon two or more face samples per mine and made since the methods of analysis were standardized in 1913 are very few. The number of workable coal beds in Ohio is about 32[20]; the number of published analyses of face samples is 457 (see following table). Of these only 34 are analyses made since 1913, each representing one sample of a group of two or more taken in the same mine. Only twenty-one mines have been sampled since 1913 at two or more places in the same mine,—one mine in the Sharon bed, three mines in the Middle Kittanning bed, four mines in the Lower Freeport bed, five mines in the Upper Freeport bed, and seven mines in the Pittsburgh bed.

These data indicate the inadequacy of existing chemical information concerning Ohio coal for the purposes of classification and for systematic construction of maps showing the distribution of variations in rank, isovols, isocarbs, etc. Many of the analyses reported represent samples collected at outcrops where the coal was likely to have been weathered and in some instances, at least, where water covered the lower part of the bed so that the sample represents only the upper part of the bed. It is impossible to determine also the conditions of sampling and to know how strictly the samplers adhered to standard methods of sampling particularly prior to about 1913.

By adopting a well organized systematic sampling program with sampling distributed as evenly as possible over the area of a bed, the number of localities sampled can be kept at the minimum in establishing accurate determinations for various geographic and stratigraphic positions. It can then be determined whether or not values vary systematically geographically and stratigraphically and to what extent Hilt's Law applies.* Some basis will thereby be provided for estimating the probable character of beds intervening between those sampled. Careful sampling and analysis should result in satisfactory township or even county averages for the different coal beds which should prove of considerable value to the

*See page 41.

ANALYTICAL DATA AVAILABLE FOR OHIO COALS

Coal Bed	Number of mines sampled[1]	Number of Analyses Made				
			U.S. Bureau of Mines[2]		Ohio Division of Geological Survey	
		Total from all sources	Bulletin No. 22	Bulletin No. 499	Report of Investigations No. 4	Fourth Series Bulletin No. 34
Total	388	457	13	21	15	408
Sharon (#1)	13	16	..	2	..	14
Bear Run	1	1	..	..	..	1
Lower Mercer (#3)	1	1	..	..	..	1
Upper Mercer (#3a)	3	3	..	..	..	3
Bedford	3	3	..	..	..	3
Tionesta (#3b)	1	1	..	..	..	1
Brookville (#4)	8	8	..	..	..	8
Winters	1	1	..	..	..	1
Clarion (#4a)	20	22	..	..	..	22
Lower Kittanning (#5)	24	26	..	..	..	26
Middle Kittanning (#6)	91	101	..	11	3	87
Lower Freeport (#6a)	12	24	4	..	..	20
Upper Freeport (#7)	52	64	4	2	5	53
Mahoning	4	4	..	..	..	4
Wilgus	2	2	..	..	..	2
Anderson	4	4	..	..	1	3
Harlem	1	1	..	..	..	1
Pittsburgh (#8)	75	103	5	6	1	91
Pomeroy (#8a)	8	8	..	..	..	8
Fishpot	2	2	..	..	..	2
Meigs Creek (#9)	45	45	..	..	4	41
Uniontown (#10)	4	4	..	..	..	4
Waynesburg (#11)	12	12	..	..	1	11
Washington (#12)	1	1	..	..	..	1

[1] Includes all analyses of both individual and composited samples.
[2] Analyses since 1913 representing 2 or more samples per mine, but not including analyses of composited samples.

coal companies, in connection with preparation procedure and in sales efforts. Accurate classification data are essential to many academic investigations. (Part III-A, 1.)

Use of punch-card system of handling chemical data. In order to make the handling of chemical data as simple as possible they should be recorded on some sort of punch-card, such as that used in the IBM* system. This system provides means of carrying on many of the calculations incident to presenting data on a variety of bases such as "as received," moisture free, ash and moisture free, etc. mechanically, and also makes possible the preparation of lists of analyses rapidly and without elaborate proof-reading. For an organization that has only a limited budget for printing this is an exceedingly important consideration. If new chemical data are continuously accumulating, these should be made available to the public at relatively short intervals and not simply once in a generation or even less often (Part III-A, 3).

Once accurate chemical information concerning Ohio coals becomes available it will become possible to assemble such data in various forms such as tables, graphs, and maps. The delineation of the distribution of variations in rank would provide information of value to the industrial and domestic buyer in the selection of coal. Even more fundamental in importance than such maps would be those indicating the distribution of variations in the moisture, and mineral matter-free or unit coal B. t. u. value which would probably provide a means for subdividing the coal field into fairly large units in which similar unit coal values prevailed for individual beds or possibly for more than one bed. Maps of isovols or isocarbs of individual beds are of practical significance in oil exploration. (Part III-A, 4, 5, 6.)

Proximate and ultimate analyses of banded ingredients and coal components. Because of the complete standardization and common use of the commercial forms of analysis in comparing, classifying, and judging coals, the validity of the distinctions between types of coals as set up by geologists will be most commonly determined by the extent to which the conventional form of analysis substantiates the distinctions. At the present time there is inadequate basis for type classification using either proximate or ultimate terms or both.

In order to obtain specific information of the chemical characteristics of the banded ingredients in Ohio coals a systematic

*International Business Machine.

sampling procedure is recommended. (Part III-A, 2, 7, and 8), the details of which are only partially suggested by the "Outline."

IV. Studies in the Fundamental Constitution of Coal

One of the peculiarities of the study of coal has been the empirical character of many investigations. Instead of considering coal as a product of the natural modification by geological processes of known kinds of plant material, just as sedimentary rocks are derived from known types of sediments, the procedure has been that of exploring the composition and properties of coal as it exists, by the application of various sorts of tests and with very little consideration of the geological history of the material. By means of these tests, many of which are extremely ingenious and not a few of which have proved of practical value, much has been learned about the properties of coal and the products yielded by the coal as a result of the tests applied. Coal has been subjected to heat in and away from the air; it has been treated with alkalies, halogens, hydrogen, oxygen, organic solvents, inorganic reagents in unremitting pursuance of the mysteries of coal constitution. In more recent years physical exploration of coal has been conducted by x-ray, thermal analysis, ultra-red and ultra-violet spectroscopy, reflectance and other light properties. Experimental tests have been applied to coals of all ranks and types for a good many years. Classification of coal into categories now regarded as representing different ranks was an early result of such empirical investigations. Similarly coking coals were distinguished from non-coking coals, and cannel and splint coals received early recognition as special varieties of coal material.

Although coal has been recognized for more than 100 years as an accumulation of a peculiar kind of fossil plant material[21], it is only within the last forty years that geologists have come to realize that coal is produced when geological forces are applied to such accumulations and that the naturalistic, rational approach to an understanding of the nature of coal and the coalification or metamorphic process is by the path of geology or geochemistry[22]. In the last two generations geologists investigating the nature of coal have contributed much information, obtained from microscopic examination of thin sections and polished surfaces of coal and of the residues obtained from chemical maceration of coal material, concerning the fossil plant organs, tissues, secretions, and products of maceration and diagenesis of peat that contributed to the initial make-up of the coal bed[23]. The geologist is concerned with the property or properties possessed in common by the diverse plant substances that apparently constitute the essential nature of coal and in the changes produced by geological influences.

Investigations of the ultimate constitution of coal in the fields of physics and physical chemistry have been fairly active in the past 10 to 15 years as new techniques of various kinds have developed (Part IV). However, the investigations have been little more than exploratory. Where these investigations are being or have been carried on by geologists or men trained in geochemistry, appropriate recognition has commonly been given to the physico-botanical makeup of the coal material, and more or less effort is made to correlate the phenomena discovered with the genetic characteristics of the coal. For example, the origin of the banded ingredients in terms of the initial plant materials is recognized and the observed physical properties are correlated with such facts, so far as possible. At certain stages in coal metamorphism the difference in the initial source and character of the coal material may cease to have any significance, but at what stage this takes place and how needs elucidation.

Investigations in the field of the fundamental constitution of coal are mainly of an academic character, because they are exploratory and the equipment necessary to carry them on is relatively expensive and likely to be scattered through laboratories in several University Departments where it may be used primarily for other purposes than the study of coal. Because of their exploratory nature investigations of the fundamental constitution of coal should appeal to young people in various fields of science, but unless such people are geologists the work to be effective should be carried on in consultation with coal geologists who can assist in the selection and identification of material studied, and can guide the work and reasoning along geological lines.

Within recent years exploratory investigations in thermal analysis of coal has been carried on more or less systematically at Massachusetts Institute of Technology[24], at the University of Arkansas[25] and at the Illinois State Geological Survey but scarcely more than a dent has been made in the problem. X-ray investigations in regard to the internal structure of coals of bituminous and higher rank coals have been underway during the current year in Urbana. Infra-red spectroscopy has been used by Breger[26] in the investigation of lignin and cellulose in the formation of coal. Reflectance

Courtesy of North American Coal Corp.

FIG. 11. A large slope mine on the Ohio River

Courtesy of North American Coal Corp.

FIG. 12. Coal loading dock on the Ohio River

has been investigated at the Bureau of Mines laboratory at Pittsburgh[27] mainly as a means of measuring the degree of coalification or vitrain. Seyler's[28] contributions in this field are well known.

If the probabilities of profitable achievement in these various fields of physical chemistry, geophysics, and geochemistry are called to the attention of young people interested in the geology of coal, research in Ohio coals parallelling and supporting that carried on in other States might result.

V. Economic Studies of the Coal Industry

A public bureau such as a state geological survey in a region of important coal production needs from time to time to take thought of the current condition of the coal industry and of the trends in mining and production as they develop. Resource studies will seek information in greater detail concerning the occurrence and distribution of the coal beds, the quality of coal available, and the changes due to mining operations. It is also appropriate now and then to have economic studies made of the markets served by Ohio coal mines, and of the transportation facilities used to carry the coal from the mine to the market. The relation of the railroads, of the steel industry, of the utilities, and river transportation (Fig. 11 and 12) are suitable topics for consideration. Strip-mining (Fig. 13 and 14) is an important although a relatively short-lived phase of the coal mining industry. Study of the economic aspects of this type of mining possibly deserves special attention in Ohio. The place of coal in the competitive fuel market and of Ohio coals in the coal market are topics appropriate for study. Attention might profitably be directed to the consideration of the recovery and marketing of coal brasses (pyrite) from Ohio coals. These suggestions by no means exhaust the list of topics appropriate for study in the field of mineral economics related to coal.

VI. Activities in the Field of Applied Research

The extent to which the Geological Survey and cooperating agencies may be expected to contribute to the welfare of the coal mining industry and to the benefit of industrial, public service, and domestic users of coal in carrying on applied research depends upon the funds, facilities, and personnel available and the policy adopted with respect to such investigations. There is an almost unlimited amount of research that could be done were "willingness and ability" adequate.

FIG. 13. Strip mine before reclamation.

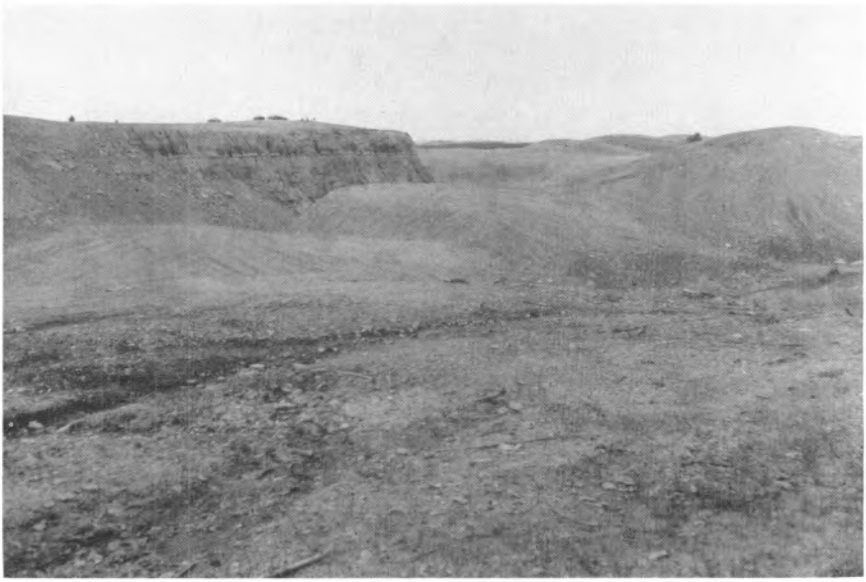


FIG. 14. Same strip mine one year later after reclamation.

Three kinds of applied research appear most desirable. These concern investigations of geological conditions affecting mine operation, coal preparation, and coal utilization.

One of the appropriate fields of activity of the Geological Survey is that of acquiring and maintaining a record of the geological conditions found in the mines of the State. Following a more or less fixed schedule of mine record data, geologists who visit mines for the purpose of sampling or for other reasons can compile specific information so that eventually the Survey will have on file a fairly complete set of notes descriptive of mining operations that will indicate where the Survey can provide helpful information to those concerned with the problems of coal extraction. The nature of roof conditions have taken on added significance in recent years because of the wide adoption of the practice of roof bolting. The effective use of this device is very largely determined by roof conditions in which geological considerations are an important factor.

The practical value of studies in coal petrography or anthracology may require some experimental laboratory demonstrations either in the field of coal preparation or in utilization. Announcement of results of petrographic studies may prompt the mining industry to carry on exploratory investigations on its own initiative, but the practical value of some discoveries may not be evident without some laboratory demonstration which it may be possible for one or more of the cooperating agencies to conduct. Thus it may be necessary to demonstrate the possibility of ingredient concentration and the value of such concentration in producing coal for certain types of utilization. Such applied research should be limited to small scale model operations, sufficient to illustrate and demonstrate the principles that are announced.

CONCLUSION

By undertaking a program of the dimensions indicated by the "Outline," the Ohio Division of Geological Survey will assume an important position in the field of coal geology. If it is possible to gain official approval of the program and the cooperating support of the coal mining industry, grounds for requesting financial support will exist.

An immediate need is for personnel to carry on a systematic study of the chemical characteristics of Ohio coals, particularly for the collection of face samples probably to the number of 150 or more possibly representing as many as 50 mines. Cooperative arrangements might possibly be made with State or Federal laboratories in connection with the chemical work if it cannot be done by the Engineering Experiment Station of Ohio State University. A sampling campaign would provide the Geological Survey with an opportunity to collect systematically scheduled observations on mining conditions in the mines sampled, which in turn would make possible a summary review of the geological conditions affecting mining in Ohio coal mines. The chemical data would provide the the basis for a correct classification of Ohio coals and for the preparation of maps showing the distribution of variations in rank and other chemical characteristics of the more important coal bed, as well as for establishing county average values in several categories.

Routine geological investigations are gradually assembling data regarding the resources represented by the individual coal beds, and such activities will provide information that will make possible the preparation of isopach maps of coal bed thickness and maps of coal bed structure.

The program in coal geology activities that has been outlined is an ambitious one for a State Survey no larger than the present Ohio Division of Geological Survey. However, it should be realized that the coal mining industry is of great importance to the state. The value of the products of the coal mines at the mines in 1950 was between $136 and $137 million at an average value of $3.70 per ton. The amount that the State has expended in coal geology investigation during the past 100 years probably does not amount to one-tenth of one per cent of the value of the coal produced for this single year. The industry is of sufficient importance to justify the expectation that coal geology will receive financial support sufficient to put a comprehensive program of research into more active operation.

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